A Proposal for an Improved Solar Still

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Abstract: The yield from solar stills depends upon meteorological parameters and design. Below improvement opportunities are presented using heat pipes. The changes may increase the yield of potable water without the need for external energy.

Introduction

Access to potable drinking water is a major problem in many parts of the world. Special need exists for small, solar-powered, portable and inexpensive desalination plants that operate in remote locations without external power. Over the past three decades, numerous designs of solar still system have been developed[1]. In all you will find the same elements: A dark, water-filled pan is heated by the sun and the contained water evaporates. The vapor condenses on the surface of an insufficient chilled glass plate and drips into a container for drinking water. The solar still is made vapor tight, as in the vapor does not escape to the atmosphere. All still designs are simple, they work completely passive, require no external energy source and have no moving parts. That is ok, but unfortunately, most of them produce relatively little drinking water per unit area. Is there room for improvement when all physically relevant details are analyzed and converted into technical solutions?

- Three key parts to evaporation are heat, atmospheric pressure and *air movement*.
- Three key parts to condensation are low temperature, atmospheric pressure and *air movement*.

An effective change of air pressure requires a lot of external energy and is not discussed in this article. Curiously, nearly all known constructions do without a forced air circulation. Dormant, vapor saturated air in the still is counterproductive, because the transport of the steam to the condenser is carried out only by slow diffusion. The numerous air molecules hinder and delay the transport of the vapor. In heat pipes (to be treated below), the tubes are evacuated, so as not to slow down the movement of the steam from the hot to the cold end of the tube.

Inside a still, even a slight air movement can greatly increase the evaporation rate by blowing away the saturated vapor layer directly over the surface. Below is described how a structural change of the still produces an effective vapor transport to the condenser without consuming additional energy.

What limits the amount of the distillate? The power of the solar radiation is about 1000 W per m². A dark absorber, 1 m² large and with a temperature of approximately 60 degrees, can collect about 500 W of thermal solar power, if it is protected against the cooling wind by a transparent plate. To evaporate one liter of water, it takes about 2.3 MJ, almost independent of temperature. Assuming a daily sunshine duration of eight hours, a 1 m² still should theoretically produce 6.2 liters of water every day. But a still of conventional design usually achieves only 3 liters. What causes this halving? Here are proposals how to improve the efficiency with simple and affordable means.

Improvements of the Absorber

The dark absorber surface of a conventional still is covered by a thin layer of water and above, there is a glass plate against the wind. Both layers partially reflect the energy of sunlight and a reduction to only one layer would be desirable. Because the thin layer of water is always horizontal, the

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absorber surface can not be tilted. Therefore, the solar energy can hardly be used in the morning and evening and tracking the variable position of the sun is impossible. If the collectors were not covered with water, the daily absorbed solar energy can be almost doubled by using three absorbers. One lies nearly flat on the floor and preferably receives the radiation at lunchtime. The other two receiver surfaces are optimized for the morning and evening hours. The energy is transferred to the boiling pan by three separate heat pipes, no absorber needs to track the sun. The diode action of the heat pipes prevents that energy is returned to unfavorably oriented or partially shaded absorbers. Heat pipes can forward the energy from distant collectors to the boiler nearly lossless.

Heat pipes

A heat pipe is long tube with extremely high thermal conductivity. It uses no moving parts and needs no external energy for the internal mechanism. Inside the hot end of the tube, a liquid is evaporated. The vapor flows in the heat pipe to the cold end and condenses back into a liquid – releasing the latent heat. The liquid then returns to the hot end through either capillary action or gravity and the cycle repeats.

For the temperature range needed in a solar still, the heat pipes are evacuated copper tubes, partially filled with water. If the tilt angle exceeds about 20 degrees, gravity pulls back the condensed water and a wick is superfluous. Horizontal heat pipes need a wick to transport back the liquid. A tilted heat pipe acts as a rectifier or a thermosyphon and transfers energy only from the lower part to the upper part, never in opposite direction.

The thermal conductivity of a heat pipe is extremely high and may reach 10^5 W/(m · K). This exceeds by far the values for copper (400 W/(m · K)) and glass (1 W/(m · K)).

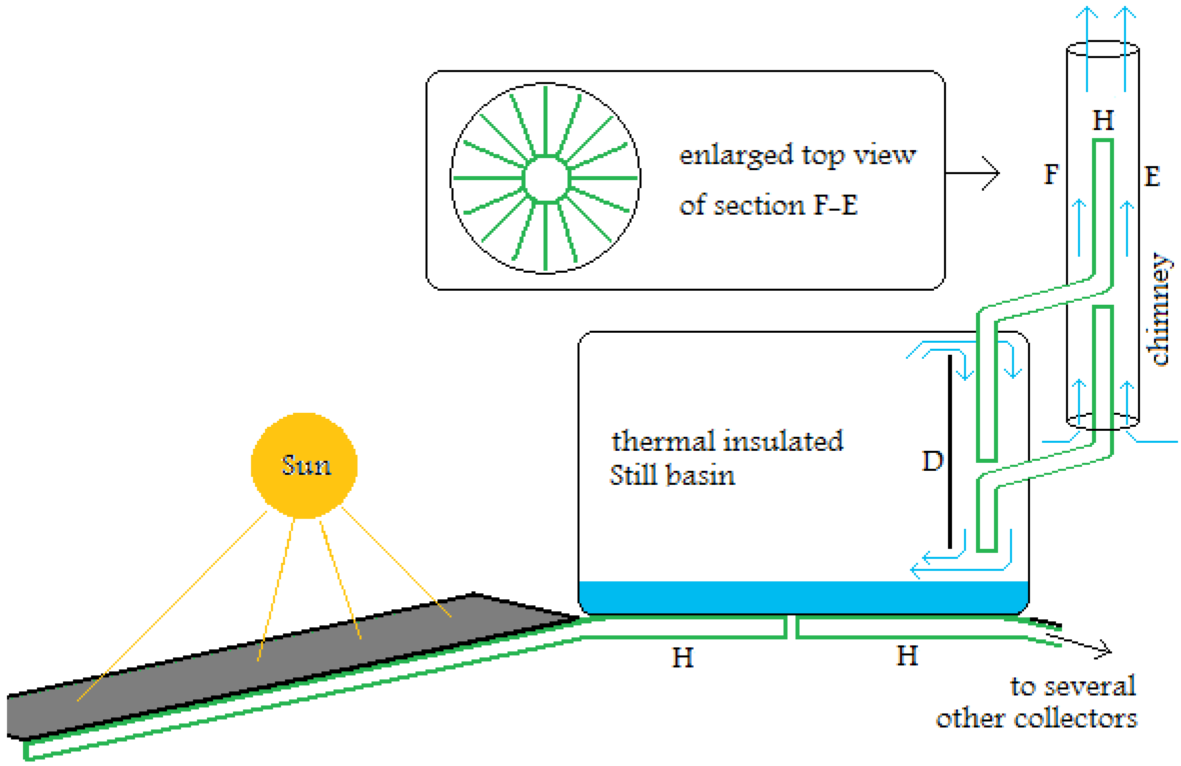
The Condenser

Most often, the boiling pan of a still is covered by a glass plate, which performs several tasks: It is transparent and allows the penetration of sunlight to heat the water. It prevents that water vapor is wasted. And it serves as a condensing surface for the vapor.

But, in addition to the water surface, the glass reflects some light energy. Due to the large area of the glass cover, the low thermal conductivity of glass is sufficient to limit the temperature difference between the two surfaces to about one degree (Plastic is unusable, as the thermal conductivity is only 0.02 W/(m · K)). The outer surface is readily cooled by the wind, but the cooling can not be improved by cooling fins, because they reduce the received radiation power. At high ambient temperatures around 40 degrees, the glass plate can hardly be colder than 50 degrees and the low temperature difference in the vapor space of the still leads to insufficient air circulation. The aim is to generate a constant convection within the still (using large local temperature differences) to blow away the saturated steam layers over the surfaces. The number of technical possibilities is limited: The temperature difference between the water and the condenser must be maximized. And air baffles must specify the path of circulation to increase the rate of evaporation and condensation without the need of a fan.

Larger and darker absorbing surfaces that are aligned with the position of the sun can raise the water temperature. Lowering the condenser temperature requires well cooled metal surfaces and wind, following the rules of the countercurrent principle. Decisive is an effective removal of condensation energy. The transport through heat pipes to a cooling tower ensures that the temperature of the condenser exceeds only slightly the ambient temperature. In the cooling tower, the natural buoyancy of heated air creates a strong air movement, replacing a fan.

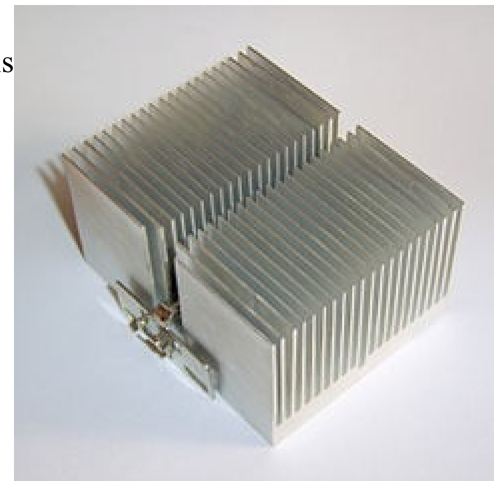
Putting it together



The picture shows how these demands can be realized technically. The heat energy of several solar collectors is transported via heat pipes (H) to a significantly smaller distillation vessel with good thermal insulation. This concentration is a way to raise the water temperature.

Near the right wall, two separate condensers (green) at different temperatures are shown. Due to cooling, the density of the air / steam mixture increases between the partition (D) and the right outer wall and the air falls down (negative buoyancy). At the lower end of this channel, the wind blows away the thin layer of vapor above the water surface and promotes faster evaporation. This is the result of the boundary layer at the evaporation surface decreasing with flow velocity, decreasing the diffusion distance in the stagnant layer. The condenser should consist of at least two separate units, because the upper one is always warmer than the lower one. The buoyancy and thus the air circulation increase, if the distiller a high, slender cylinder like typical industrial distillation towers.

The condensation energy of both condensers is transported through heat pipes to a high chimney. Inside the tube, the air is heated and moves upward due to buoyancy forces. The draft in the chimney improves the cooling of the built-in heat exchangers. Of course, the proposed shape of the cooling fins can be adjusted to the Chimney cross-section.



Commercial heat sinks of corrosion resistant aluminum are available in many shapes and sizes. They are well suited as a condenser in the distillation chamber and as a convector in chimney because the heat pipes can be easily mounted.

[1] S. Yadav, K. Sudhakar, Different domestic designs of solar stills: A review, 2015, https://www.researchgate.net/publication/274254208_Different_domestic_designs_of_solar_stills_A_review#feedback/311630